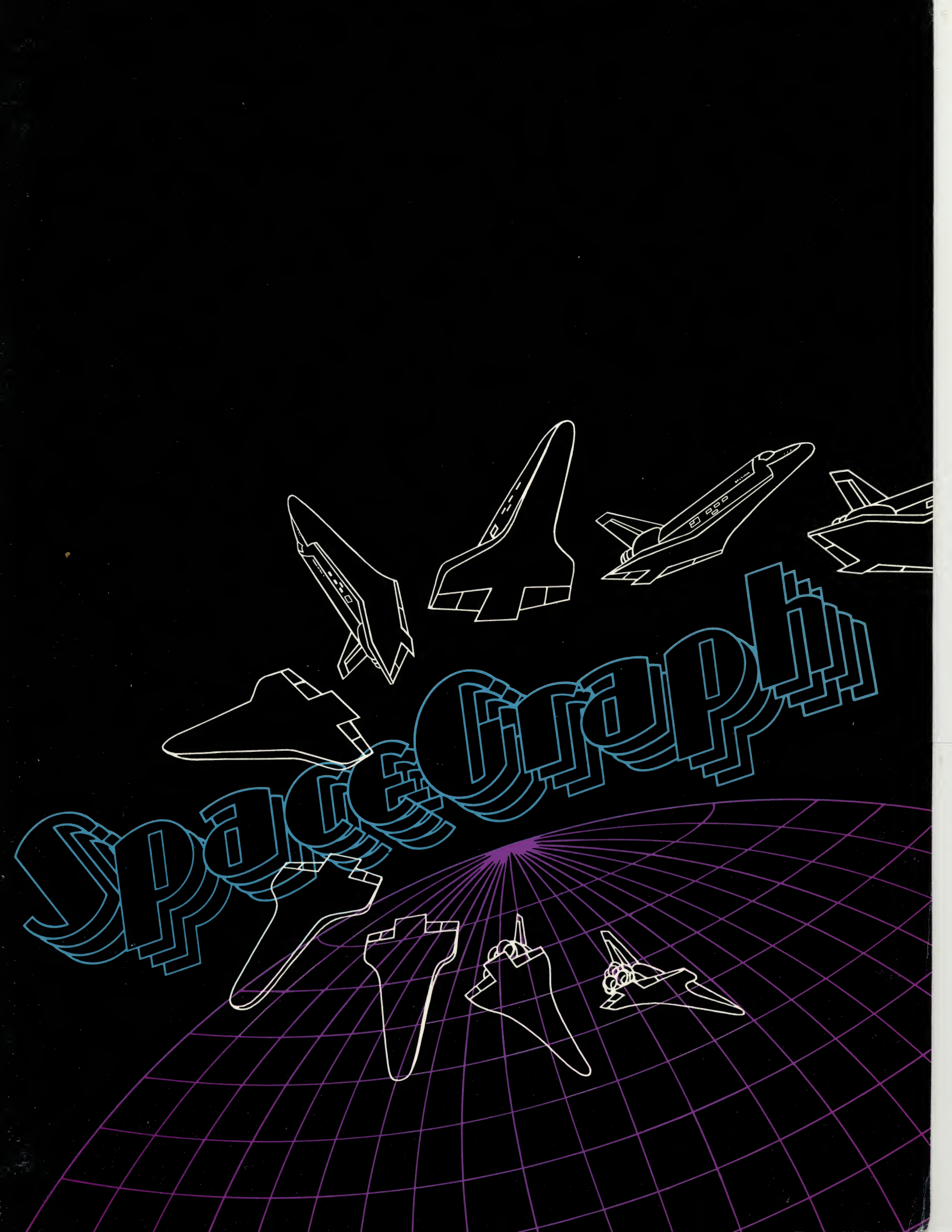
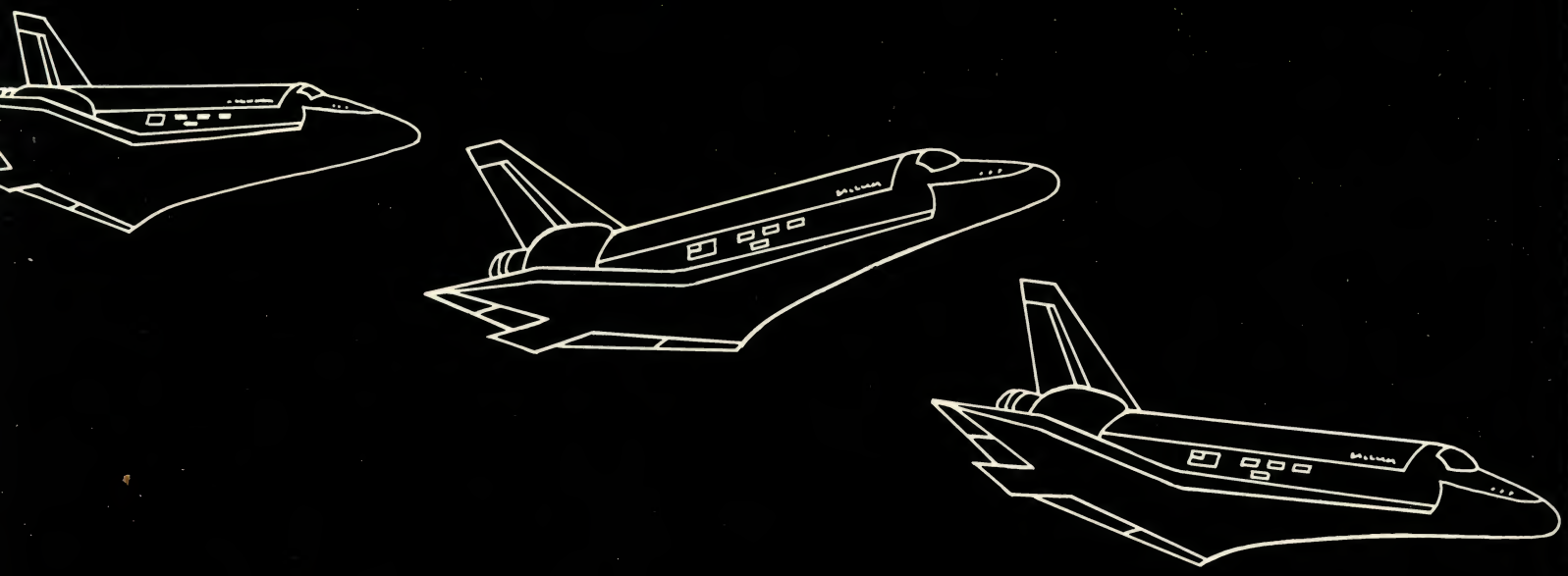

Spacegraph

# SpaceGraph™ – the true 3D display system... for generation of image, contour, vector and alphanumeric data in gray scale or black and white.



The SpaceGraph display system makes 3D image creation a living tool because SpaceGraph is a fully realized product (not an educational model or an R&D prototye). The system provides space-filling graphics and images in a display volume. And SpaceGraph performs this unique function with resolution, performance and interactivity generally superior to that of raster graphic displays. To the user this means that within the SpaceGraph display volume of 20 cm x 25 cm x 30 cm, the operator can view an image with resolution of 4096 x 4096 x 16,384 (depth). By moving his head the operator can see a new angle of the image and using keyboard control he can interact with the 3D image.

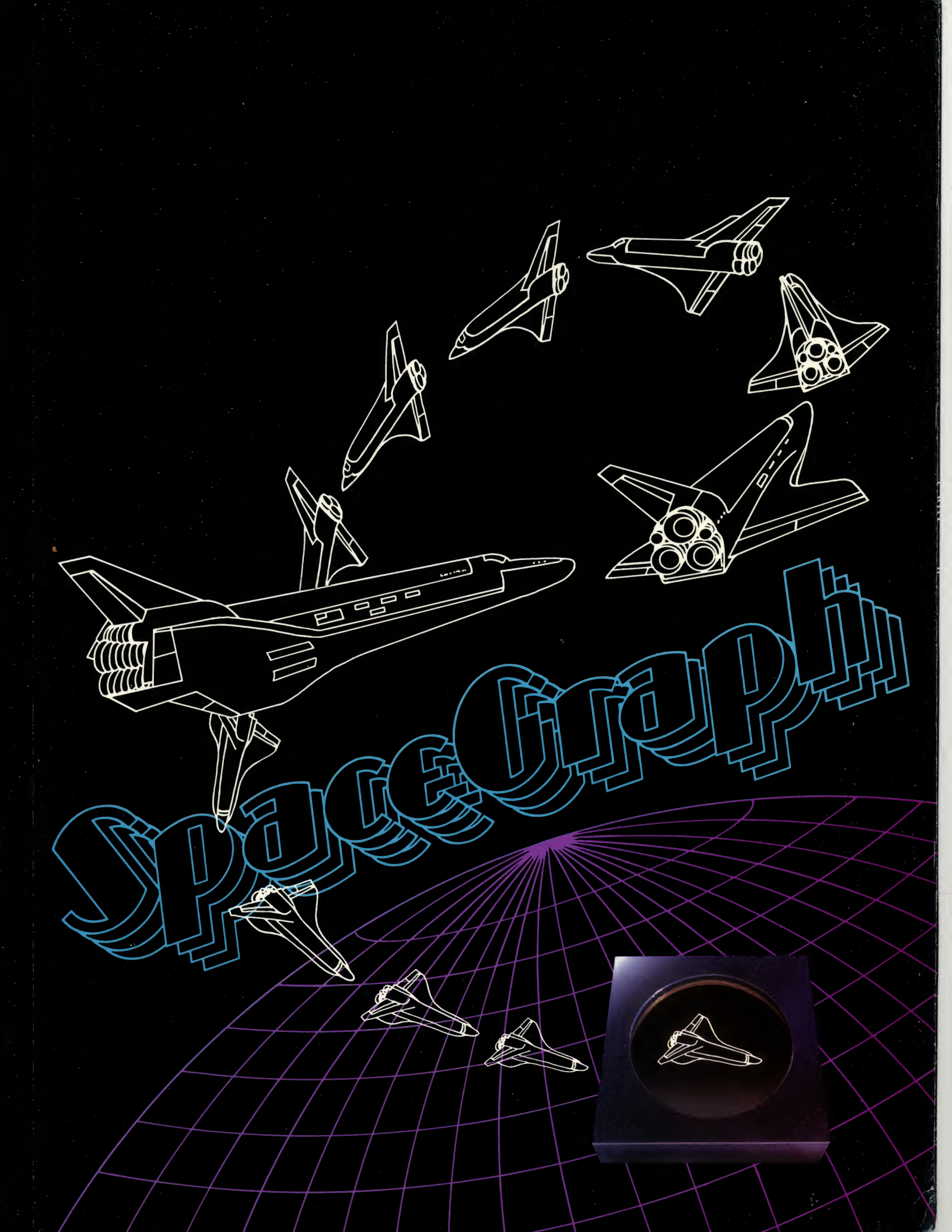
## Who Needs 3D and Why?

Three dimensional display has a number of significant, sometimes indispensable, advantages for a wide range of applications.

- **Objectivity:** a SpaceGraph image does not require the viewer's biases, personal skills or viewpoint (which are subject to error) in order to interpret the depth cues. Therefore, the viewer sees the image with objectivity even if he has little or no previous knowledge of the subject.
- **Three dimensional plotting:** using brightness as one parameter, each point on a SpaceGraph display can represent four variables (like temperature, humidity, wind speed and wind direction). Therefore, all interdependencies of these parameters are clearly visible to the viewer.
- **Display of previously undisplayable data:** subjects such as a fluid flow field or a complex structure with internal movement which cannot be adequately represented on flat displays can be effectively displayed on SpaceGraph.
- **Dimensional matching of graphics to subject:** interacting with a SpaceGraph space-filling image is "natural"—curved lines are shown as such, through-holes can be seen through. Since depth is explicit, hidden line removal is not required as a depth cue, and no subjective interpretation is required to determine data in this z dimension. The viewer can deal directly with the meaning of the data rather than trying first to determine what the data is.
- **Quick understanding of subtle data:** all of the above advantages make it possible for the viewer to grasp data far more quickly with 3D. Therefore, decisions about the data can be made within the pressing time requirements of demanding applications such as air traffic control or nuclear plant control.

While a 3D interactive display will no doubt contribute to most graphics applications, the unique advantages of a third dimension are particularly valuable in some fields:

- Geophysical exploration and seismology
- Computer-aided tomography (CAT) scan
- Computer aided design (CAD)
- Oil reservoir management
- Molecular research
- Training and education
- Military command and control
- Anti-submarine warfare
- Ultra sound diagnostics
- Air traffic control
- Process control
- Meterology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## The Third Dimension

SpaceGraph produces three-dimensional images and graphics by the reflection of a standard CRT image in a vibrating, variable focal length mirror (see Figure 1). Under control of a high-speed graphics computer, the timing of the image on the CRT screen is coordinated with the position of the mirror so that individual planes of the object or scene are reflected at progressively deeper positions of the mirror image. The retentive characteristics of the human eye bind the planes together and, by refreshing each plane at a 30Hz rate, the graphic/image appears to be suspended in space. The volume in which the object appears in 20 x 25 x 30 cm. Since the mirror is much wider (40 cm) than the display, the viewer can see some side view of the object by head movement to either side of center as much as 30 degrees.

**Reliable:** The SpaceGraph system has only two moving parts, the mirror and its drive. The driving power for the mirror plate is a hifi woofer which requires only a few watts of power for operation and is highly reliable. And the total movement of the mirror at its center is only ±2mm.

**Interactive:** SpaceGraph's main utility is that it presents information in a truly three dimensional form. However, its power as a workstation is that it allows the viewer to interact with the display by enhancing areas of the object by changing brightness or blinking. It also allows the viewer to rotate the display, scroll through the display in the z axis and other types of interactivity provided in the basic system. In addition, it offers the capability to the user to write interactive routines of his own.


## A New Dimension in Electronics

SpaceGraph's unique optical system is transformed into a working product by a state-of-the-art electronics package. While SpaceGraph may be controlled by a host computer, the system also contains an ultra-high performance graphics computer. Thus, the high speed graphics functions of SpaceGraph can be performed locally at the terminal, thereby offloading the host and increasing the system's responsiveness and interactive capability.

The system computer (called the Advanced Display Computer/ADC) is a Genisco-designed processing system which incorporates a bipolar bit slice/ALU with direct decoding programmed logic array. The advanced architecture of the ADC makes possible instruction times as fast as 160 nanoseconds with word transfer rates to 3 MHz. Data and program storage totals 128K bytes in standard configuration.

The computer offers a set of more than 140 instructions among which is a powerful block transfer capacity. This instruction allows for the transfer of up to 128K bytes at a single command at speeds as high as 3 MHz between the host and the ADC, the ADC and the graphics refresh memory (256K bytes) or between host and refresh.

## Dual Mode System Operation

SpaceGraph functions in two operating modes. The first is graphics mode, which displays "stick figures" that is, vectors and points in a 3D array such as might be used in CAD, and the other is image mode which shows actual pictures or images as would be required for CT data.

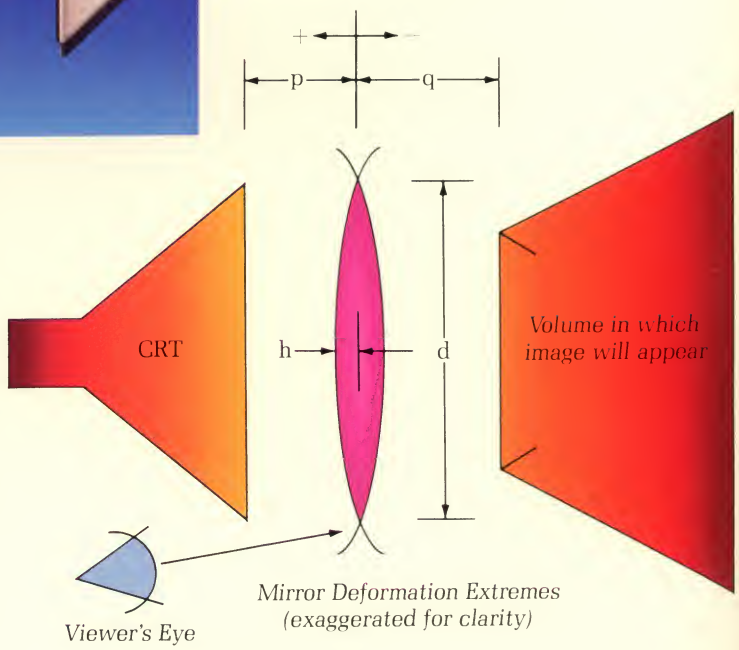
**Graphics Mode:** In graphics mode, the SpaceGraph system receives initial graphics display data from an external source, generally a host computer. This data is decoded and converted to generate display parameters for one or more dualported refresh memories. These memories are scanned 30 times a second to produce the display output.

To envision the graphics mode the user can imagine the z axis (depth) being divided into 32,768 time slices each being a plane in x, y. Vectors are drawn and points plotted by illuminating one picture element (in 3D called a voxel for volume element) per plane in up to 32,768 planes. The element may be located anywhere in the 4096 x 4096 x, y plane. There are more than one-half trillion possible voxel positions of which any 32,768 can be displayed at one time.

The operator can control any portion of the graphics mode sequence by means of keyboard commands and can request a wide range of interactive operations. Vectors, characters and points can be added or deleted, intensified or blinked with the aid of a 3-axis joystick plus the simple keyboard commands. A special software feature performs automatic scaling and centering to provide maximum use of the available volume.

**Figure I:**

*The figure below shows the SpaceGraph concept, exaggerating the mirror deformation for clarity.*




*p = object distance (fixed)*
*q(t) = image distance*
*h(t) = amplitude of mirror deflection at center*

**Image Mode:** In image mode, image display data is transferred directly from a host computer to the SpaceGraph refresh memories over a high speed DMA channel. Complex 3D images are shown as planes of data (each plane being flat to the point of view) stacked one behind the other. Both the size of the planes in the x, y dimension and the number of planes in z are selectable by the user. The total volume element capacity in the image mode is 262,144 voxels per each refresh cycle. The matrix size of each plane can vary from 64 x 64 with 64 planes to 256 x 224 for 4 planes. The number of voxels in the x dimension is variable in increments of 16 voxels. The number of lines in the y axis is variable in integers.

Keyboard controls allow deleting any number of planes from the front or back to provide a clearer view of inner volumes. Planes can be selected sequentially in any block size to provide a means of scrolling through the volume. The scanning rate is controlled by keyboard entries. A control is also provided to vary the distance between planes.

In both graphic and image modes, each pixel of a plane has an 8 bit intensity value. A programmable translation table allows real time selection of any of 128 shades of gray for each voxel. The translation table can be programmed so that any voxel or group of voxels can be blinked or blanked upon command. Thus, the user can intensify, deintensify or blink any area of the 3D graphic/image for maximum ease of recognition.

The graphics and image modes can be combined allowing images, graphic structures and characters to be intermixed. This is accomplished by writing the graphics during the forestroke of the mirror and the image during the backstroke.

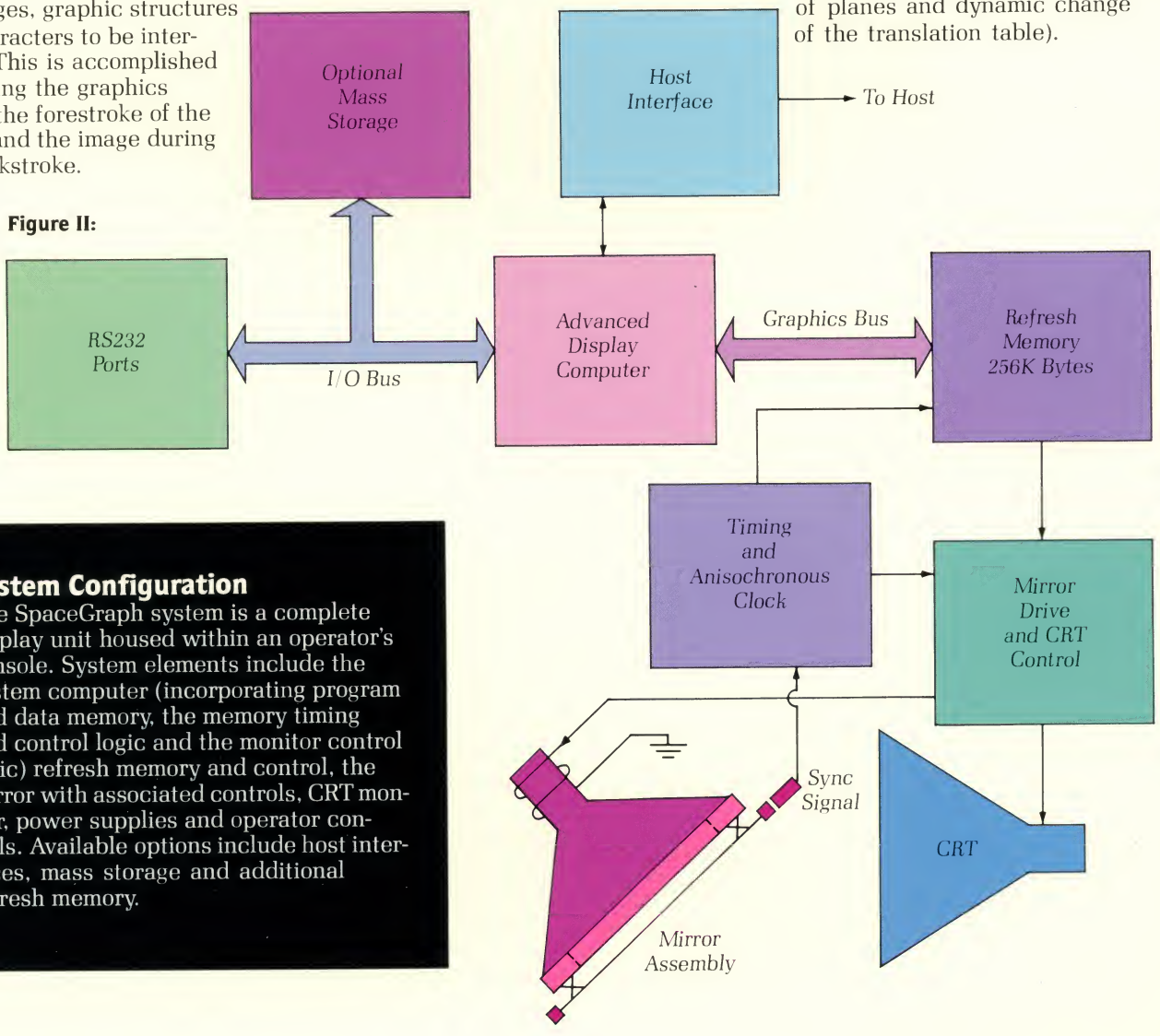
## The Software System

SpaceGraph is designed in both hardware and software to act as a satellite workstation which can offload the graphics function from the host. In some applications, the system may act as a stand-alone terminal. The system will function in three software modes: a display terminal mode wherein data is played back from either remote or local mass storage; a mode in which commands are received through a keyboard or other interactive device through the SpaceGraph computer (ADC); or, in a "combination" mode which allows receiving of commands under host control with some functions performed at the ADC and some at the host. This last mode is ideal for users who have applications software in the host but still want to take advantage of the local interactive capability of the SpaceGraph system.

The modular design of the SpaceGraph software makes the system highly flexible for a wide variety of applications. The user can do programming in high level language on the host or write routines in ADC assembly language to be executed in the SpaceGraph system.

Software subroutines for processing of the database will perform functions described in the Siggraph Graphics Standard (CORE) including such functions as selecting view, clipping and transforming the database. Additional functions are added to the Siggraph standard in order to take advantage of the extensive capability of the SpaceGraph system (for example, the interactive highlighting of planes and dynamic change of the translation table).

**Figure II:**




## System Configuration

The SpaceGraph system is a complete display unit housed within an operator's console. System elements include the system computer (incorporating program and data memory, the memory timing and control logic and the monitor control logic) refresh memory and control, the mirror with associated controls, CRT monitor, power supplies and operator controls. Available options include host interfaces, mass storage and additional refresh memory.

## SpaceGraph Specifications

### System Components

| | |
|---|---|
| Work station: | CRT, mirror assembly, alphanumeric monitor, keyboard, 3 axis joystick |
| Electronics Cabinet: | Genisco ADC, RS232 8-port board, 2 refresh memory boards, digital clock board, mirror drive and CRT control board, optional mass storage |

### Display Characteristics

| | |
|---|---|
| Volume: | 25(X) x 20(Y) x 30(Z) cm max.<br>Z depth selectable |
| Resolution: | Graphics mode: 4096(X) x 4096(Y) x 32,768(Z)<br>Image Mode:<br>X up to 256 voxels variable in increments of 16<br>Y up to 256 lines variable by integer<br>Z Number of Planes = $\frac{262{,}144}{\text{X voxels x Y lines}}$ |
| Display Points: | Graphics mode: 32,768 voxels<br>Image mode: 262,144 voxels |
| Intensity: | 128 gray shades plus blink or blank |
| Video Lookup Table: | 256 x 8 |
| Z-axis Scroll Resolution: | .5 mm |
| Refresh Rate: | 30 Hz |

### Hardware Specifications

| | |
|---|---|
| CPU: | Genisco ADC 16 bit high speed minicomputer, 112K bytes RAM, 16K bytes PROM; 160 nsec instruction time |
| Refresh Memory: | 256K bytes; optional 512K bytes |
| Mirror Size | 40 cm diameter |
| Mirror Frequency: | 30 Hz |
| Monitor Size: | 25(X) x 20(Y) cm |

### Physical Characteristics — Work Station

| | |
|---|---|
| Width: | 60 inches (152.4 cm) |
| Height: | 76 inches (193 cm) |
| Depth: | 30 inches (75.2 cm) |

### Power Requirements

120V, 60Hz, 6.2A

Genisco

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